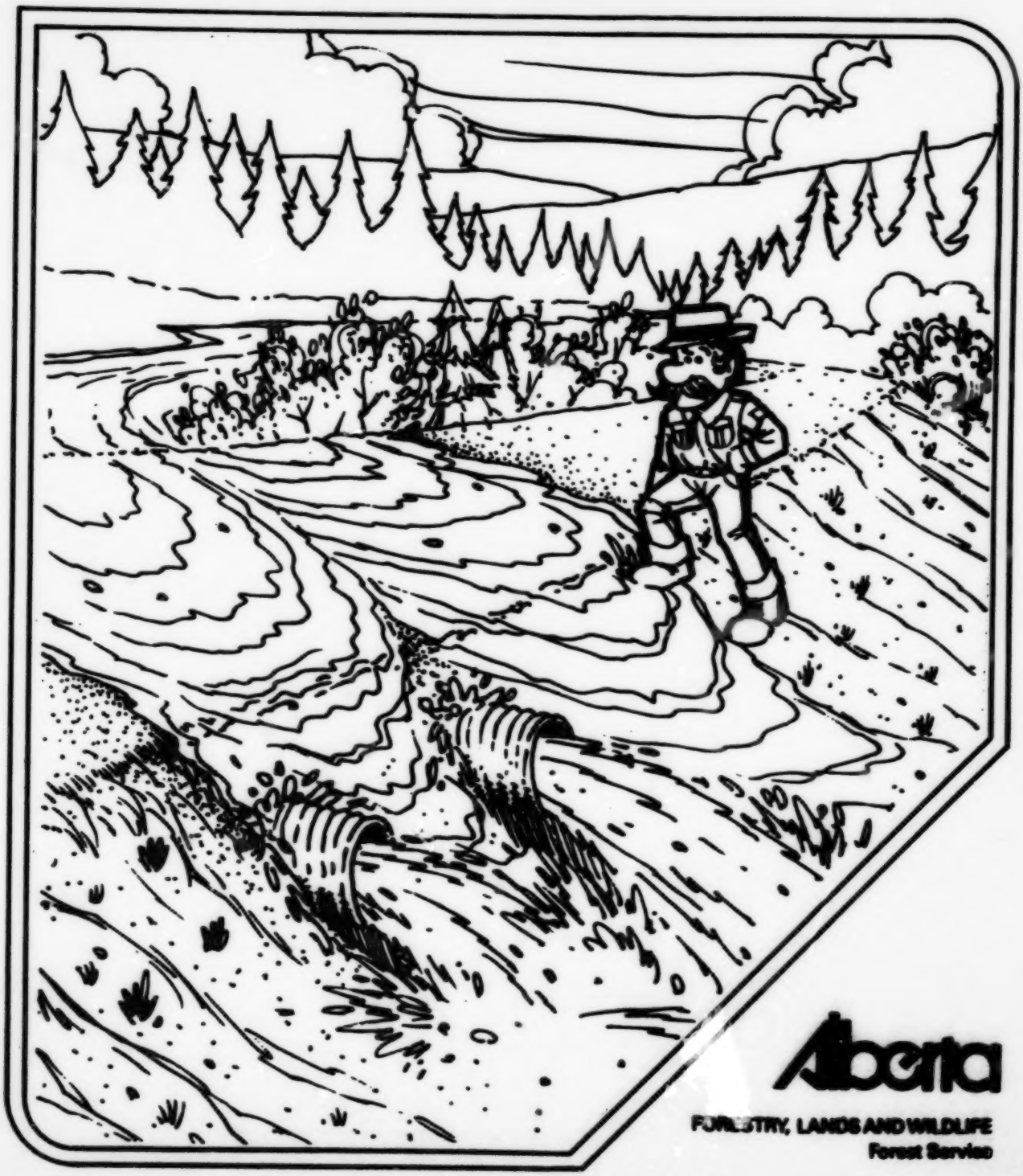
Culvert Sizing for Stream Crossings

A Handbook of Three Common Methods



Alberta

FORESTRY, LANDS AND WILDLIFE

Forest Service

SIZING CROSSINGS FOR EASTERN SLOPE STREAMS

A HANDBOOK OF THREE COMMON METHODS

by
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1. INTRODUCTION

Improperly sized stream crossings can be a problem. Culverts too small to handle large storm flows result in failure and the associated problems of lower water quality, loss of fish and stream habitat, interruption of traffic flow and expensive repairs. Too large a crossing involves unwarranted construction, engineering and material costs. The extra engineering involved may require more clearing and stream modification, resulting in further deterioration of stream habitat. Most stream crossings are designed to handle a storm or peak flow of a given return period because of the potential cost of crossing failure. Temporary crossings of less than two years are usually designed to survive 25-year peak flows (Truck Logger 1972), while more permanent crossings should be designed to handle a 50-year or even 100-year peak flow (Fisher 1985).

The purpose of this report is to outline three common methods used for determining 25-year peak flows and note their advantages and disadvantages. Recommendations on the validity of each method will be made, based on practicality, availability of input data and accuracy of peak flow estimate. The methods used include:

1) Fish and Wildlife sizing technique
2) Burkli-Ziegler formula
3) Rational formula

No method can be considered absolutely true but should be expected to provide a better perspective on the general magnitude of 25-year peak flows. These estimates should be further modified by the additions of safety factors and tempered by personal knowledge of the area. The recommended procedure for estimating peak flows is as follows:

1. Visit the site; a field inspection can give clues to peak flows. Look at other crossings on the stream. Were they of adequate size?

2. If possible, take a flow measurement at a high stage. A high stream discharge can be used for comparison against your estimate.

3. Complete the Fish and Wildlife sizing technique and either the Rational formula or the Burkli-Ziegler formula.

4. Choose a crossing size. Ultimately, the estimate of peak flow relies heavily on judgment and common sense, with the application of suitable safety factors. If the sizing techniques estimate similar size flows then confidence is increased in your estimates.

2. FISH AND WILDLIFE CULVERT SIZING TECHNIQUES

This simple technique uses the stream's cross-sectional area (at bank-full stage) to estimate the size of crossing required. The level of bank-full stage is determined by observing the location of high water marks or, more preferably, the top of the unvegetated channel. Care should be taken in determining this level as high-water marks may not coincide with the stage that actually occurred at the time of peak flow. High water marks may have occurred during spring runoff when ice in the stream channel would have created artificially high stage. Debris caught in the branches of small trees or brush may be unreliable high water marks because current could have forced the branch to bend, and later, upon straightening, an artificial stage height is recorded (Hewlett 1982). Also, the surface of a stream in flood is not a flat plane and the associated turbulence makes high water marks only an approximation of the true stage height (Chow 1964). Furthermore, a stream that is rising will scour material and later deposit it during its recession (Linsley 1983). While this method is simple to perform, its only parameter, the cross-sectional area, must be carefully judged.

METHODS

FIELD MEASUREMENTS

1) Select a straight section of stream to conduct measurements.

2) Locate level of bank-full discharge by looking for high water marks or the top of the unvegetated channel.

3) Stretch a measuring tape across the stream perpendicular to the flow to establish the cross-section transect.

4) Set up surveying level in a position with visibility of entire transect.

5) Using the surveying rod and level, record readings every 0.5 m starting at the bank where the level of bank-full stage was established and continuing across the stream until a similar reading on the rod is reached (see Table 1).

CALCULATIONS

1) Calculate stream cross-sectional area (m^2).

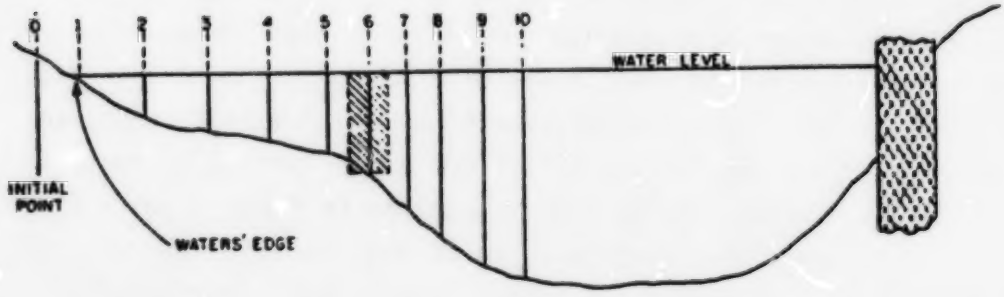

Figure 1. Stream Cross Section

a) Calculate depth (m) of the water by subtracting the initial reading on the rod (distance = 0) from all other readings.

b) Calculate the area of each measured panel by multiplying each panel depth by its width (m^2).

c) Sum the area of all panels to obtain the stream's cross-sectional area (m^2).

2) The culvert cross-sectional area (Ac) equals twice the bank-full cross-sectional area

ie. Ac = 2 X Stream Cross-Sectional Area

3) Culvert diameter (Dc) = $2\left(\sqrt{\frac{Ac}{\pi}}\right)$

= metres

4) If desired, this can be converted to flow by using a form of the Manning equation (Rothwell 1978) or from a culvert sizing table (Table 2).

Table 1
Cross-Section Measurements

(a) Distance From Shore(m)	(b) Rod Height (m)	(c) Panel Depth (m)	(d) Panel Area (m^2)
0	0.903(*)	0	0
0.5	1.300	0.397	0.1985
1.0	1.345	0.442	0.2210
1.5	1.348	0.445	0.2225
2.0	1.375	0.472	0.2360
2.5	1.372	0.469	0.2345
3.0	1.361	0.458	0.2290
3.5	1.285	0.382	0.1910
4.0	1.314	0.411	0.2055
4.5	1.277	0.374	0.1870
5.0	1.224	0.321	0.1605
5.5	1.108	0.205	0.1025
5.7	0.905	0.002	0.0010
			=2.189 m^2

Panel Depth (Column c) = Rod Height (Col. b) - Initial Rod Height (*)
Panel Area (Column d) = 0.5 m x Panel Depth (Col. c)

$Q = \frac{(.375\sqrt{Dc})(\sqrt{S})}{3.207\ n}$ where Dc - diameter of culvert (m)

S - slope of culvert = 0.017

n - roughness coefficient for culvert = 0.021

Q - discharge (m^3/s)

Table 2. Culvert diameters (m) for a given peak flow and culvert slope. Culvert diameters were determined using a form of the Manning equation (Rothwell 1978).

Streamflow (m^3/s)	Slope of Culvert (%)					
	1.0	1.2	1.4	1.6	1.8	2.0
0.50	0.67	0.64	0.62	0.61	0.60	0.58
1.00	0.86	0.83	0.81	0.79	0.77	0.76
1.50	1.00	0.97	0.94	0.92	0.90	0.88
2.00	1.12	1.08	1.05	1.02	1.00	0.98
2.50	1.22	1.18	1.14	1.11	1.09	1.07
3.00	1.30	1.26	1.22	1.19	1.17	1.14
3.50	1.38	1.33	1.30	1.26	1.24	1.21
4.00	1.45	1.40	1.36	1.33	1.30	1.27
4.50	1.52	1.47	1.42	1.39	1.36	1.33
5.00	1.58	1.52	1.48	1.44	1.41	1.39
5.50	1.63	1.58	1.53	1.50	1.46	1.44
6.00	1.69	1.63	1.59	1.55	1.51	1.48
6.50	1.74	1.68	1.63	1.59	1.56	1.53
7.00	1.79	1.73	1.68	1.64	1.60	1.57
7.50	1.84	1.77	1.72	1.68	1.64	1.61
8.00	1.88	1.82	1.77	1.72	1.68	1.65
8.50	1.92	1.86	1.81	1.76	1.72	1.69
9.00	1.97	1.90	1.85	1.80	1.76	1.73
9.50	2.01	1.94	1.88	1.84	1.80	1.76
10.00	2.05	1.98	1.92	1.87	1.83	1.80
10.50	2.08	2.01	1.96	1.91	1.87	1.83
11.00	2.12	2.05	1.99	1.94	1.90	1.86
11.50	2.16	2.08	2.02	1.97	1.93	1.89
12.00	2.19	2.12	2.06	2.01	1.96	1.92
12.50	2.22	2.15	2.09	2.04	1.99	1.95
13.00	2.26	2.18	2.12	2.07	2.02	1.98
13.50	2.29	2.21	2.15	2.10	2.05	2.01
14.00	2.32	2.24	2.18	2.12	2.08	2.04
14.50	2.35	2.27	2.21	2.15	2.11	2.06
15.00	2.38	2.30	2.24	2.18	2.13	2.09
15.50	2.41	2.33	2.26	2.21	2.16	2.12
16.00	2.44	2.36	2.29	2.23	2.19	2.14
16.50	2.47	2.39	2.32	2.26	2.21	2.17
17.00	2.50	2.41	2.34	2.29	2.24	2.19
17.50	2.52	2.44	2.37	2.31	2.26	2.22
18.00	2.55	2.46	2.39	2.33	2.28	2.24
18.50	2.58	2.49	2.42	2.36	2.31	2.26
19.00	2.60	2.51	2.44	2.38	2.33	2.28
19.50	2.63	2.54	2.47	2.41	2.35	2.31
20.00	2.65	2.56	2.49	2.43	2.38	2.33
20.50	2.68	2.59	2.51	2.45	2.40	2.35
21.00	2.70	2.61	2.54	2.47	2.42	2.37
21.50	2.73	2.63	2.56	2.50	2.44	2.39
22.00	2.75	2.66	2.58	2.52	2.46	2.41
22.50	2.77	2.68	2.60	2.54	2.48	2.43
23.00	2.80	2.70	2.62	2.56	2.50	2.45

SAMPLE CALCULATION - WAMPUS CREEK

1) Bank-full cross-sectional area - 2.19 m^2 (from Table 1)

2) Culvert cross-sectional area = Ac = 2 X Stream cross-sectional area
= 4.38 m^2

3) Culvert diameter =Dc = $2\sqrt{\frac{Ac}{\pi}} = 2\sqrt{\frac{4.38}{3.14}} = 2.36$ m

4) Discharge = $Q = \frac{(.375\sqrt{Dc})(\sqrt{S})}{3.207n} = \frac{(.375\sqrt{2.36})(\sqrt{.017})}{(3.207)(.021)} = 19.1\ m^3/s$

Advantages

- quick and simple technique to use
- does not require estimate of any coefficients
- calculates crossing size directly
- involves measuring the actual stream
- does not need precipitation data, which is often difficult to obtain
- does not require historical streamflow data

Disadvantages

- assumes all streams of a given cross-sectional area are hydrologically similar. This ignores: basin size, basin shape, soil type, precipitation, slope, vegetation and land use activities

- difficult to determine where bank-full discharge level occurs
- selection of transect for measuring cross-sectional area critical for success (i.e. stream width changes constantly, obstacles in stream will reduce stream's cross-sectional area).

3. BURKLI-ZIEGLER FORMULA

The Burkli-Ziegler formula includes drainage area, a runoff coefficient, slope and rainfall intensity as additional factors contributing to discharge. This relationship has been used with satisfactory results by the Engineering division of the British Columbia Forest Service since 1964 (Forest Club, UBC 1971) and is described by:

$$Q = \frac{Aci\left(\frac{S}{A}\right)^{.25}}{14.39}$$

where Q - peakflow (m^3/s)
A - drainage area (km^2)
i - rainfall intensity (mm/hr)
c - runoff coefficient (Table 3)
S - average slope of main channel in metres per 1 000 m

Unfortunately one weakness of the Burkli-Ziegler formula is its inclusion of a runoff coefficient. Obviously, the selection of an appropriate runoff coefficient is critical for success. The UBC Forest Club (1971) has adopted values from European sources and considers them representative of alpine and montane regions in B.C. As shown in Table 3, the coefficient varies according to the type of terrain and its slope and represents a percentage of the water contributing to streamflow by overland flow.

SAMPLE CALCULATION

WAMPUS CREEK

1) Watershed Area (A) = 28.2 km^2

2) Select Runoff Coefficient (c) = 0.30 Alpine Forest, Middle Slope

Table 3

Runoff Coefficents For The Burkeli-Ziegler Formula

Burkeli-Ziegler formula (after Forest Club, UBC 1971)				
		Runoff Coefficients for		
Elevation	Character of land	Flat 0-20%	Middle Slope 20-50%	Steep Slope 50%+
		C	C	C
Above Timberline	Meadow	0.40	0.60	0.80
	Rock	0.50	0.70	0.90
Alpine forests	Forest	0.20	0.30	0.50
Hilly to flat country	Meadow	0.10	0.30	0.50
	Forest	0.50	0.15	0.30

(Rothwell 1978)

3) From Appendix I determine 25-year return period 60 min. rainfall intensity.

Edson region (i) = 38.1 mm/hr

4) Obtain average slope (S) of main channel from topographic maps in metres/1 000 m.

Wampus = 18.9 m/1 000 m

5) Calculate peak flow

$$Q = \frac{Aci\left(\frac{S}{A}\right)^{.25}}{14.39}$$

$$= \frac{(28.2)(.30)(38.1)\left(\frac{18.9}{28.2}\right)^{.25}}{14.39}$$

$$= 20.27\ m^3/s$$

where Q = peak flow (m^3-s)
A = watershed area (km^2)
c = runoff coefficient
i = rainfall intensity (mm/hr)
S = slope - m/1 000 m

6) Culvert diameter required = 2.41 m (Table 2).

Advantages

- does not require personnel to travel to stream
- input parameters easily determined from maps

Disadvantages

- relies on runoff coefficient for peak flow estimate
- assumes rainfall contributes to streamflow through overland flow
- only designed for small watersheds (up to 13 km^2)
- difficult to get good precipitation information

4. RATIONAL FORMULA

This widely used formula was originally developed for peak runoff in storm sewers by Kuichling in 1889 and is often used for predicting peak flows from small watersheds (up to 13 km^2). Like the Burkli-Ziegler formula, the rational formula makes a direct mathematical link between peak flow and drainage area. However, it also notes the influence of slope and length of the main channel, roughness of the stream channel, time for water to travel through the watershed, and the effect of different rainfall intensities and durations upon discharge (Rothwell 1978).

The rational formula is:

$$Q = \frac{CiA}{3.630}$$

Where:

Q = peak flow (m^3/s)

i = rainfall intensity (mm/hr) of a storm for a given return period, whose duration is equal to the time of concentration

A = watershed area (km^2)

C = runoff coefficient (Table 6)

In respect to rainfall intensity, the rational formula is unique as it incorporates the concept of time of concentration (Tc). This is defined as the time it takes for water in the most remote point of the drainage basin to reach the point of study (i.e. stream crossing, outlet). At the time of concentration, and assuming uniform rainfall intensity throughout the basin, the rate of runoff equals the rate of water influx from precipitation (Chow 1964). Past this point, additional rainfall does not affect the magnitude of peak flow but rather only prolongs its duration (Rothwell 1978). Empirically the time of concentration (Tc) is defined as:

$$\log Tc = \frac{\log\left(\frac{2187.33\ L\ n}{\sqrt{S}}\right)}{2.14}$$

where L = Maximum length of travel of water (km)

OR

$$Tc = \sqrt{\frac{2187.33\ L\ n}{\sqrt{S}}}^{2.14}$$

n = roughness coefficient of watershed

S = slope of main channel

From the time of concentration the corresponding rainfall intensity is determined from a rainfall intensity - duration curve for the appropriate return period and location (Figure 1).

As with many peak flow formulae the Rational includes the concept of a runoff coefficient (C). It does have the advantage that coefficients can be combined by multiplying them by their percentage of occurrence. The sum of these weighted runoff coefficients then represents an average value for the watershed (see Table 4).

As with any model a number of assumptions are made, under which the model should perform satisfactorily. For the Rational formula these assumptions are:

a) for the duration of a storm, the rainfall intensity remains uniform.

b) the rainfall is uniformly distributed over the watershed.

c) C remains constant for storms of different return periods and for all storms on a particular watershed.

d) the storm duration is sufficient to equal or exceed the time of concentration.

e) maximum flow occurs once rainfall intensity has equalled or exceeded the time of concentration.

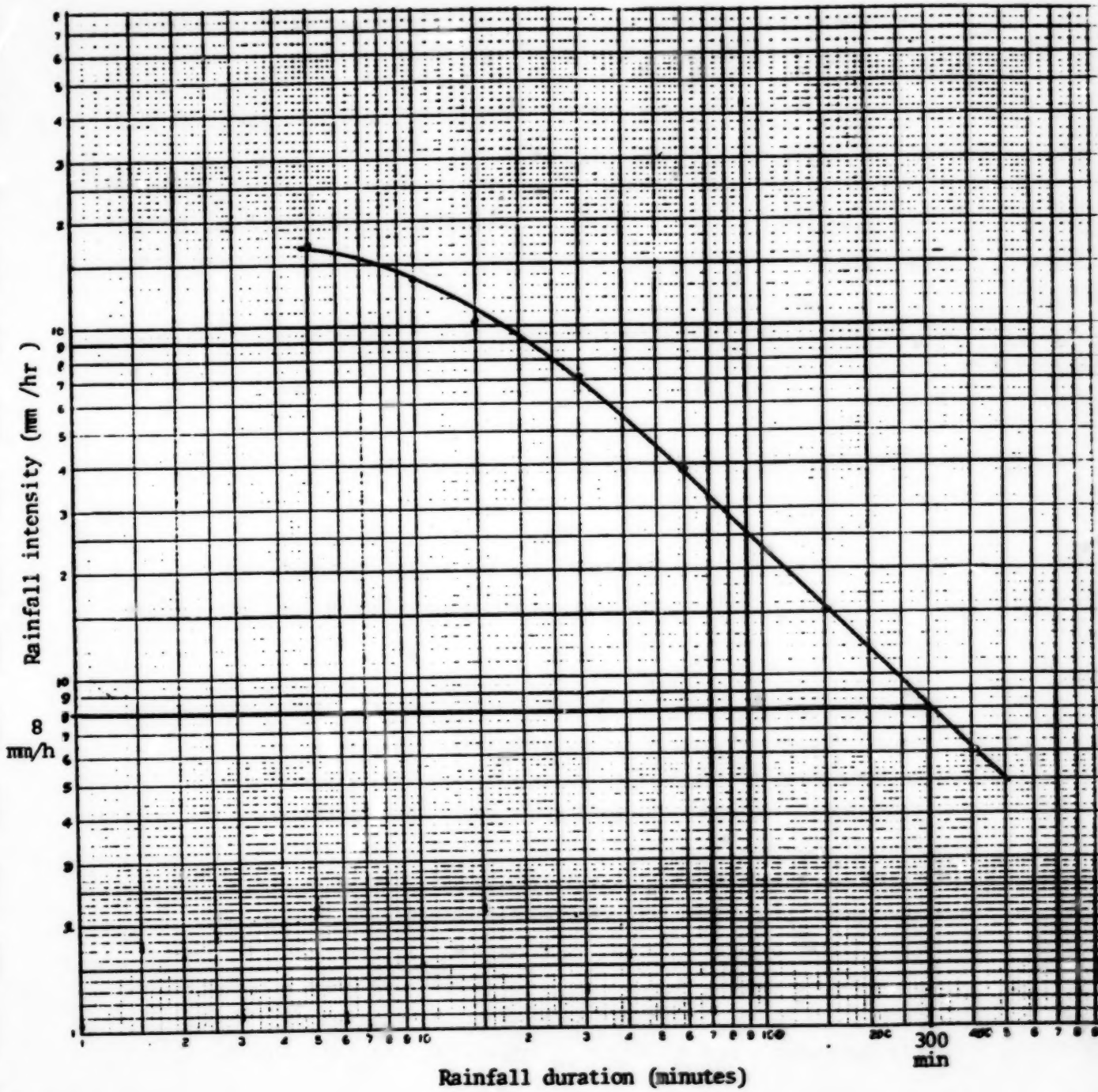

Fig. 2: Graphed result of rainfall duration (min.) vs. rainfall intensity (mm/hr)

f) once peak flow occurs all areas of the watershed contribute equally to stream discharge.

g) return period of peak flow is the same as the return period of the rainfall intensity that caused it.

h) rainfall intensity is more important than the amount of precipitation.

i) land use activities have no impact.

METHODS

1) Select roughness coefficient of watershed (n)

Table 4

Roughness Coefficients for the Rational Formula

(after Bruce-Clark 1966)

Type of Surface	Value of n
Smooth, impervious.....	0.02
Smooth, bare, packed soil.....	0.10
Poor grass, row crops, or moderately rough bare soil.....	0.20
Pasture.....	0.40
Deciduous timberland.....	0.60
Coniferous timberland or deciduous timberland with deep litter or grass.....	0.80

2) Determine maximum length of travel of the main channel (L) in metres

3) Determine slope of stream channel (S)

- The difference in elevation between the watershed outlet and the farthest point from the confluence divided by the stream length.

4) Calculate the time of concentration (Tc) by:

$$Tc = 2.14 \sqrt{\frac{2187.33\ L\ n}{\sqrt{S}}}$$

L = length of stream (km)
n = roughness coefficient
S = average slope of stream

5) Derive a rainfall intensity-duration curve for the return period and area of interest from the maps in the Appendix using the following method:

i) identify the general location of the watershed under study on the maps of Alberta (Appendix)

ii) for each map, from the isohyetal lines, determine the rainfall in millimetres (see Table 5)

iii) on full-log paper plot rainfall intensity (mm/hr) against rainfall duration (minutes) (Figure 1). Extra sheets of full-log paper are supplied in the Appendix.

Table 5

EXAMPLE - EDSON REGION (Rainfall duration determined from maps in Appendix)

25-year return period

RAINFALL DURATION (Min.)	RAINFALL (mm)	RAINFALL INTENSITY (mm/hr)
1 440 min.(24 hr)	76.2	3.2
60 min.	38.1	38.1
30	36.6	73.2
15	25.4	101.6
10	22.9	137.4
5	14.2	170.4

6) Extrapolate rainfall intensity (mm/hr) from calculated time of concentration for desired return period.

7) Select runoff coefficient for drainage basin.

Table 6

Runoff Coefficient for Rational Formula

Rational formula (after Frevert et al. 1955)			
Topography and Vegetation	Open sandy loam	Clay and silt loam	Tight clay
	C	C	C
Woodland			
Flat (0-5%slope)	0.10	0.30	0.40
Rolling (5-10%slope)	0.25	0.35	0.50
Hilly(10-30%slope)	0.30	0.50	0.60
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82

(Rothwell 1978)

8) Calculate peak discharge

$$Q = \frac{CiA}{3.630}$$

Q - peak flow (m^3/s)
C - runoff coefficient (Table 6)
i - rainfall intensity (mm/hr)
A - watershed area (km^2)

SAMPLE CALCULATION

WAMPUS CREEK

1) Roughness coefficient of watershed n=0.80 (Table 4)

2) length of main channel (L) = 15.8 km

3) Average slope of main channel (from topographic maps) S = .0189

4) Calculate time of concentration

$$Tc = 2.14 \sqrt{\frac{2187.33\ L\ n}{\sqrt{S}}}$$

$$= 2.14 \sqrt{\frac{(2187.33)(15.8)(0.80)}{\sqrt{.0189}}}$$

$$= 300.8 \text{ min.}$$

5) From Figure 2

Rainfall intensity (i) 25-year return period for Tc = 300.8 min.
i = 8 mm/hr.

6) Select runoff coefficient (C) = 0.35 Topography-rolling woodland with clay and silt loam (Table 6)

Calculate peak discharge

$$Q = \frac{CiA}{3.630}$$

Q = discharge (m^3/s)
i - rainfall intensity (mm/hr) (Figure 1)
C - runoff coefficient (Table 6)
A - watershed area = 28.2 km^2

$$Q = \frac{(0.35)(8.13)(28.2)}{3.630}$$

$$= 22.1\ m^3/s$$

Culvert diameter required = 2.49 m

Advantages

- input parameters can be easily determined from maps
- runoff coefficients can be combined to give an average value for entire watershed

Disadvantages

- requires selection of a runoff coefficient
- only designed for small watersheds (up to 13 km^2)
- temporary water storage, which can lower or delay peak flows, is not considered
- assumptions hold only in small and highly impermeable areas (e.g. paved areas) but applications to other drainage basins may be questionable
- requires more work than most formulae (i.e. determination of Tc)
- runoff coefficients change for each storm
- all areas of a watershed do not contribute equally to runoff; some do not yield any storm flow while others contribute significantly depending on antecedent soil moisture.
- Tables of runoff coefficients do not consider that C increases with higher return period storms (due to infiltration and other factors having a proportionally smaller effect on peakflow) (Chow 1964)

5. DISCUSSION

It must be realized that calculated 25-year peak flows are only estimates. Taken collectively they can only serve as a guide to the selection of a properly sized crossing. For maximum crossing safety the largest estimated peak flow could be selected, but the validity of this estimate may be questionable. Instead, it is a better practice to use a more moderate estimate and, if several values are in close agreement, so much the better. Still, these estimates cannot be expected to provide a complete solution to the problem, as they must be tempered by the local experience and professional knowledge of the persons involved.

After a 25-year peak flow estimate has been determined, select the proper sized culvert from Table 2. Fisher (1985) suggests that for flows greater than 8.5 cubic metres per second (culvert diameter 1.74 m) a bridge should be considered.

The crossing still may not survive all 25 year peak flows because of icing, debris jams and future land use activities. Forest debris and icing can reduce the cross-sectional area of the crossing resulting in flooding and crossing failure. Debris problems may be alleviated by constructing debris barriers and regularly cleaning the crossing. Similarly, icing can be prevented by steaming culverts in the spring and installing larger culverts where problems exist. However, none of these techniques consider the influence of various land use activities on peak flow. For example, logging can increase the water input to a stream and thereby alter the timing or magnitude of peak flow. An increase of 35% or more in total annual flow was found following timber removal in Oregon (Harr 1979). In the Hinton area, Swanson and Hillman (1977) predicted 20 to 30% increases in annual yield and increases in storm flow peak magnitude of four to five times.

It is generally considered that logging can increase peak flows by a factor of 1.5 although higher return period storms may exert less of an influence. Table 7 estimates the extent of other influences on peak flow. These factors are only a crude approximation of a complex system so judgment is required to decide whether their application is warranted. Hetherington (1974) recommends the application of a standard safety factor by selecting a culvert size "one or two sizes larger than that necessary to handle the design flow".

Table 7
CULVERT SIZING SAFETY FACTORS

Safety factors should be applied when study watershed has one or more characteristics in the flashy column

FLASHY CHARACTERISTICS	——AS OPPOSED TO—— NON-FLASHY CHARACTERISTICS	SAFETY FACTOR (multiply by estimated peak flow)
1) large (extensive) areas of bogs and fens adjacent to the creek (greater than 40% of area)	Mineral soil adjacent to the creek	2.0
2) logging and other land-use clearing (50% area lost)	Forested	1.5
3) Steep basins (greater than 20%)	Flat basin (less than 1%)	1.5
4) Very shallow coarse soils	Very deep soils	2.0
5) High drainage density	Low drainage density	1.25
6) Narrow basin	Wide basin	1.25
7) Abundance of roads	No roads	1.1
8) Icing	No icing problem	2.0

Factors may be multiplied together but do not exceed two times.

GLOSSARY

antecedent soil moisture - soil water content existing or occurring before a storm

bank-full stage - discharge with a stage height corresponding to the top of the unvegetated channel. State of flow in a river or creek when, because of the high volume of water, no river banks are exposed.

cross-sectional area - the area (m^2) of a vertical plane of water measured at right angles to the flow. It represents the "average" maximum flow as the channel has developed from the interaction of storms and runoff over time. The stream channel is an expression of the average range of flows.

empirical formula - a mathematical relationship based on factual information, observation or direct experience showing the simplest ratio of parameters

evapotranspiration - loss of water from the soil both by evaporation from the surface and by transpiration from the plants (movement of water through the plant to the atmosphere)

Gumbel paper - an exponential function presented graphically that is used in flood frequency analysis

icing - the buildup of ice inside or around a stream crossing. The resulting reduction in the cross-sectional area of the crossing can result in flooding and crossing failure

isohyetal lines - lines on a map relating to or indicating equal rainfall

overland flow - water that flows over the surface without infiltrating the soil at any point

peak flow - maximum instantaneous discharge (m^3/s)

permanent crossing - stream crossing designed for year round use for greater than two years

return period - the average length of time separating events of similar magnitude.

stage - the level of water in a creek or river channel above a given datum.

storm flow - total amount of water produced from a storm

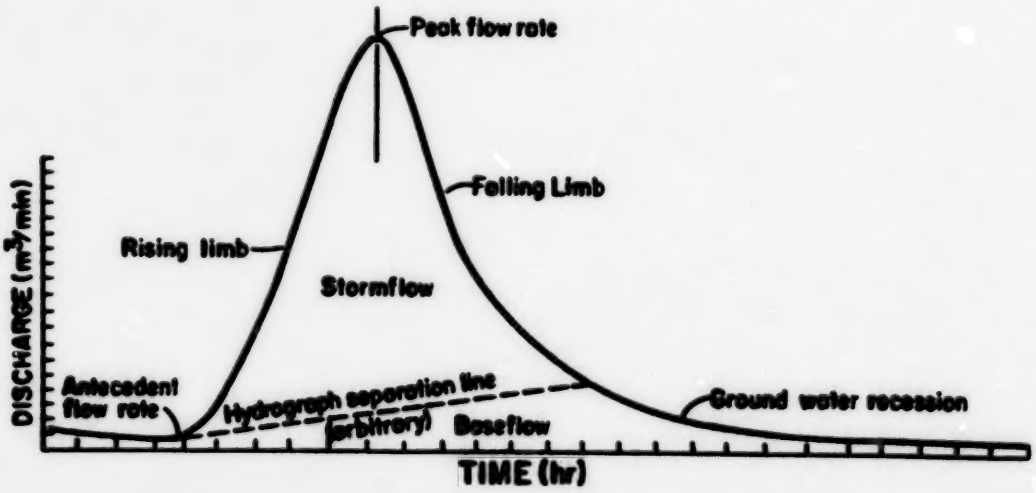

Fig. 3 Stormflow hydrograph (from Hewlett 1982)

subsurface flow - water that moves laterally through the topsoil into the stream

surface flow - often confused with overland flow but differs as its water may have been subsurface water at one time

temporary crossing - a stream crossing used on a seasonal or short-term project basis for less than two years

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APPENDIX I

ADDRESSES OF DATA SOURCE AGENCIES

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T2P 2M7

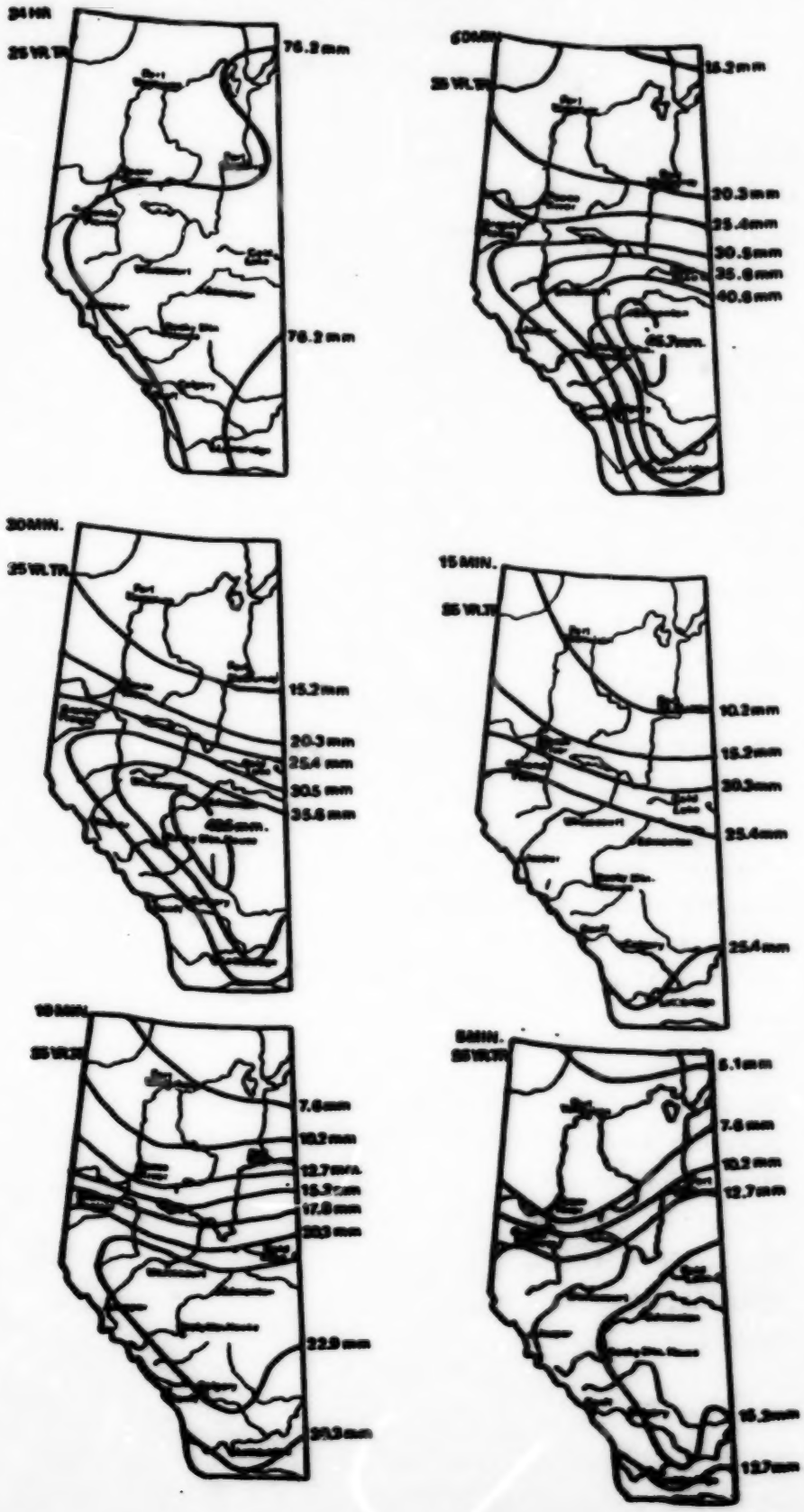
2) Director,
Water Resouces Branch,
Department of the Environment,
OTTAWA, Ontario,
K1A 0E7

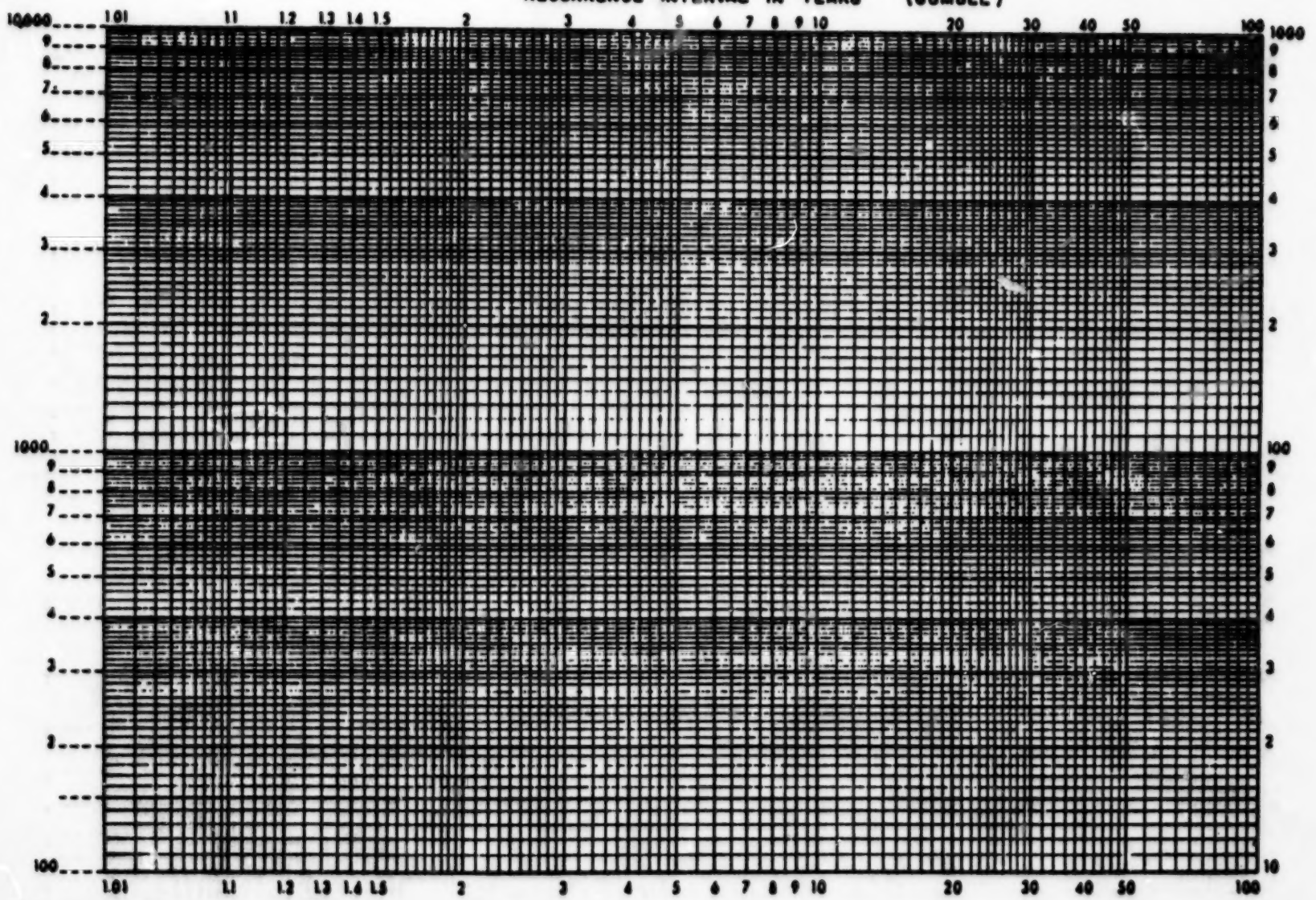
3) Watershed Management Section
Forest Land Use Branch
Forestry, Lands and Wildlife
Main Floor
Petroleum Plaza, North Tower,
9945 - 108th Street
EDMONTON, Alberta
T5K 2G6

4) Director,
Technical Services Division,
Alberta Environment
10th Floor, Oxbridge Place
9820 - 106th Street,
EDMONTON, Alberta
T5K 2J6

Appendix II

FIG. 4: 25-YEAR RETURN PERIOD RAINFALL INTENSITY-DURATION MAPS
(adapted from Bruce 1968)

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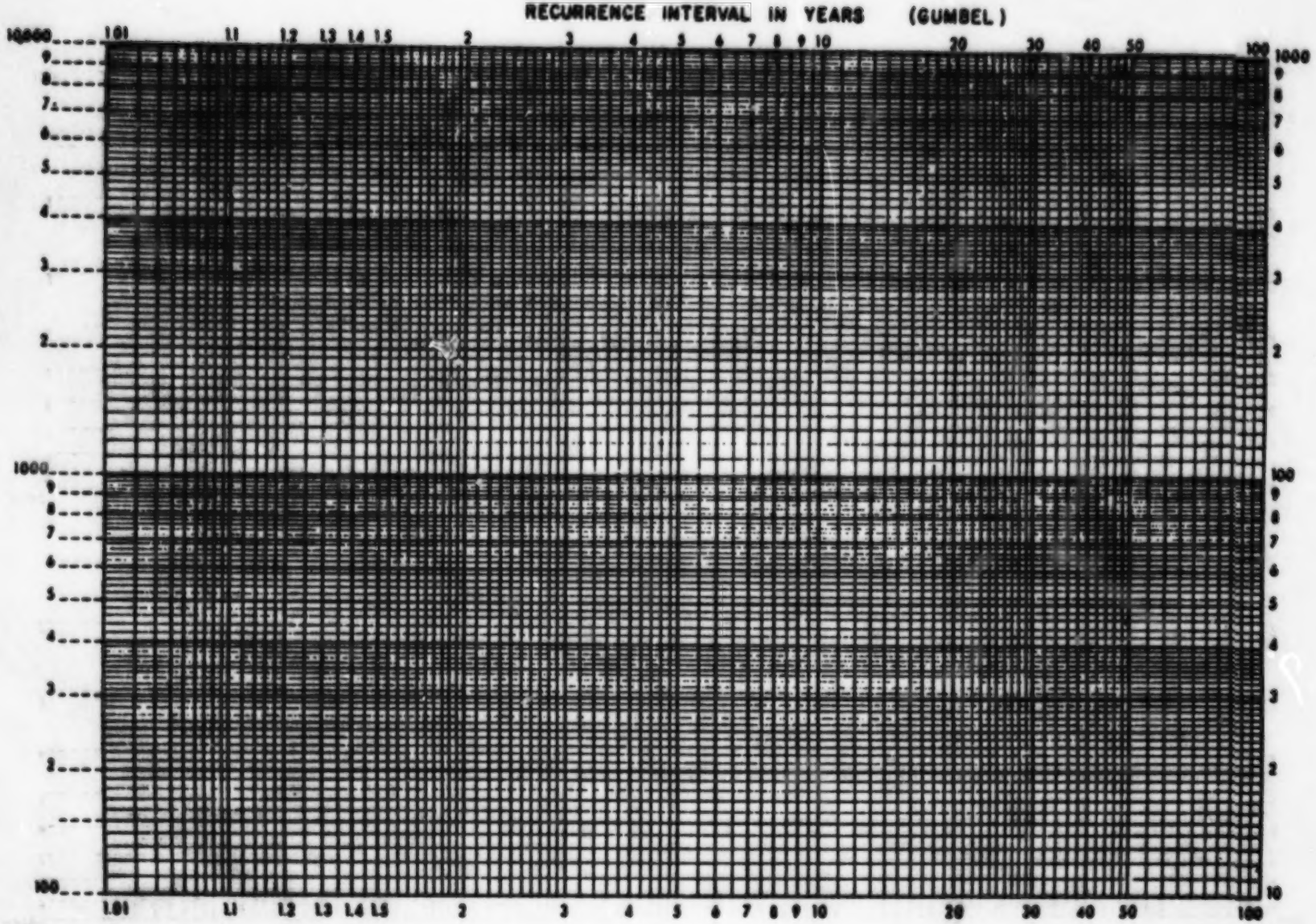
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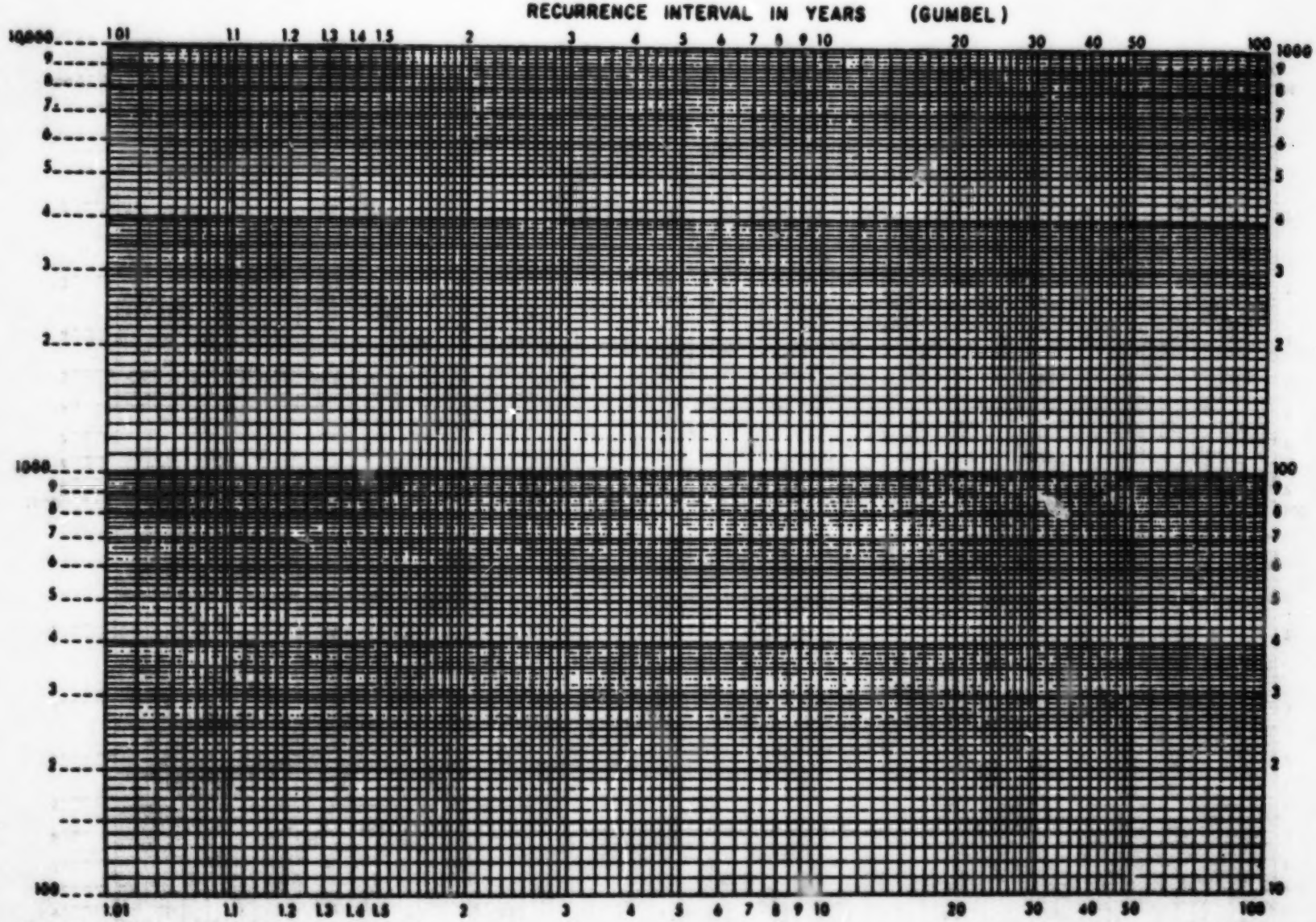
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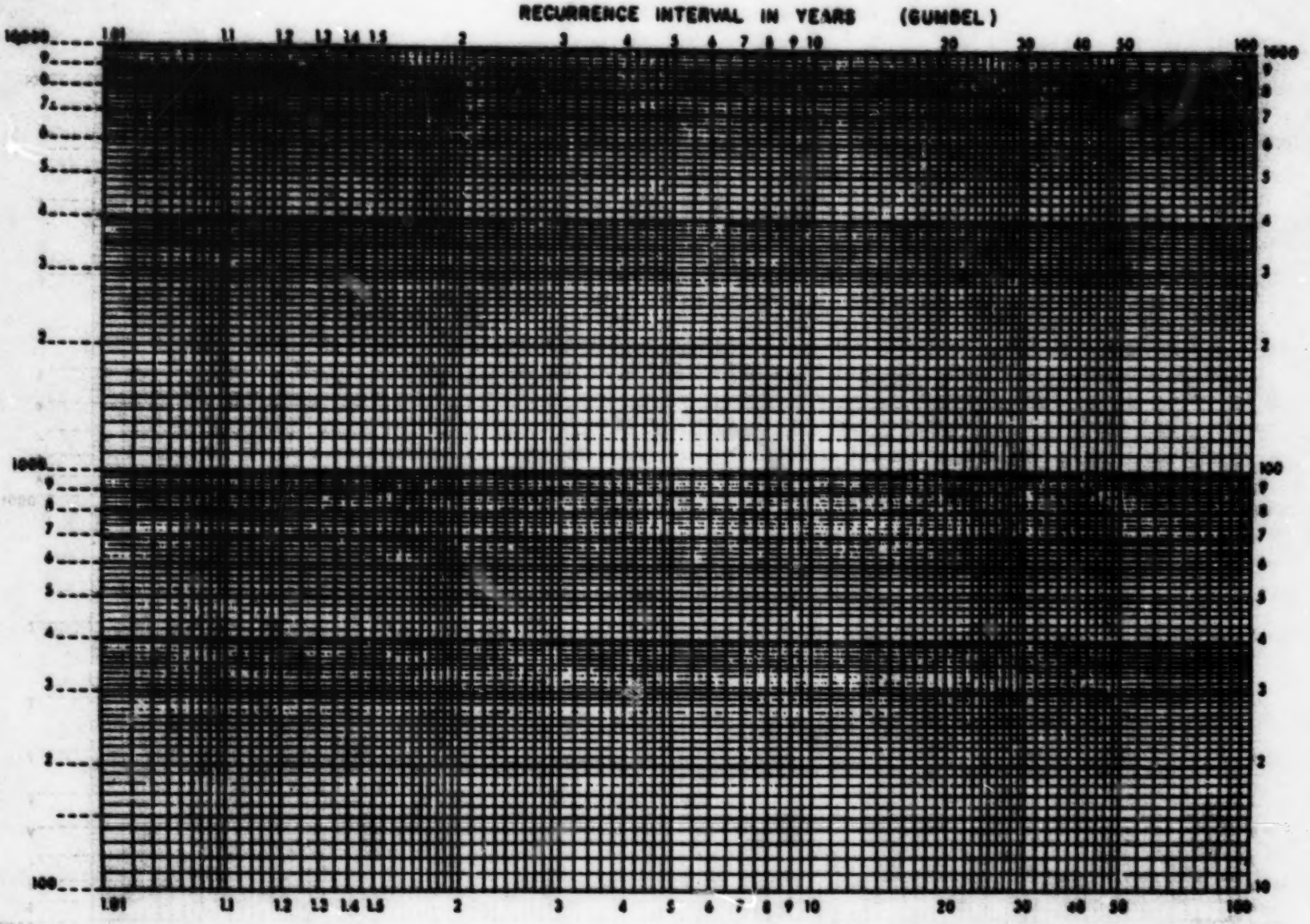
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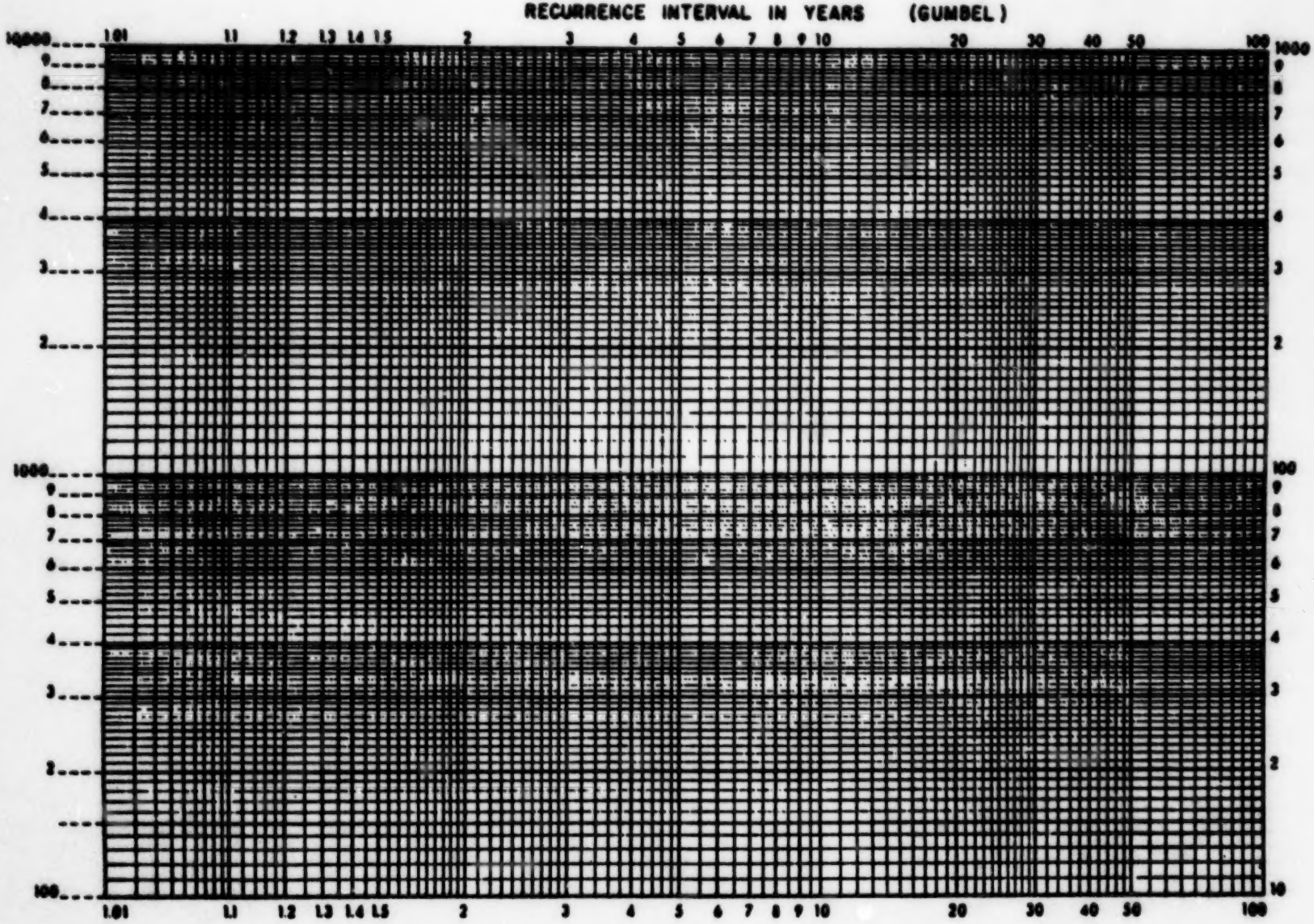
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